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Letter to the Editor

Techno-economic analysis of solar parabolic trough type energy system for garment zone of Jaipur city

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ABSTRACT

Energy crisis and environmental problems require a new sustainable energy supply option that uses renewable energies and is economic at the same time. Solar Thermal Power (STP) generating systems are proven renewable energy technologies and often a very cost effective way to produce electricity from solar radiation. In this paper, the potential and the cost-effectiveness of a parabolic trough collector (PTC) type solar thermal power plant for meeting the energy demand of garment zone at Sitapura industrial area, Jaipur is analyzed. In this, the present energy demand of garment zone, design of proposed solar power plant and economic evaluation of the power plant has been carried out. The estimated energy requirement of the selected garment zone was 2.21 MW for year 2011. To meet the present energy demand and expected increase in the demand a PTC type solar power plant of 2.5 MW capacity is proposed, which require about 15.76 acres of land area and has 256 solar collector elements. Looking to the scarcity and cost of the land near the city, off-site proposal of the power plant has also been considered and compared with on-site option. Four economic scenarios were analyzed for the proposed system and their financial performance is evaluated. For the onsite solar power plant internal rate of return is 19.21%, NPV at 10% discount rate is 372.77 million INR, simple payback period is 5 years and discounted payback period @10% is 7 years and 4 months, while for the off-site power plant IRR is 27.85%, NPV is 550.55 million INR, simple payback period is 3 years and 6 months and discounted payback period is 4 years and 7 months. Levelised cost of energy (LCOE) for onsite power plant is Rs 9.41/kWh and for offsite power plant is Rs 6.89/kWh.

1. Introduction

The garment zone of Sitapura industrial area is situated in southern part of Jaipur in Rajasthan state of India. Garment zone comprises of forty four industries. The main product of the zone is cotton cloths. The process of the industries in garment zone is sewing cloths from fabric. These industries use different machines and power presses. Sewing machines, power presses, interlocking machines, hydro machines (create wrinkles), washing machines and drier machines are mainly used by these industries. Machines and lightning equipments consume energy in the form of electricity while power presses consume steam. In the industries electricity is outsourced from grid and steam is produced locally by diesel fuel fired boiler. Electricity is needed to run machines, lighting equipments, and cooling equipments such as fan and air conditioners. Industries also have diesel generators as standby power supply source.

The average energy demand of the garment zone is 1.84 MW_e but it varies from month to month. Energy demand for January to April and October to December is higher than monthly average demand while for May to September it is lower than Average demand due to off session. Nowadays continuous supply of energy is becoming largest problem for industries especially for garment sector and their production gets affected by frequent power cuts. The backup diesel generators have very high operation cost due to price rise of diesel and on the other hand it is not a clean source of energy. So there is a great need for sustainable source of energy and solar energy is the largest available carbon-neutral energy source. Mekhilef et al. [1] studied the utilization of solar energy systems for industrial applications and looked into the industrial applications which are more compatible to be integrated with solar energy systems. Gupta [2] worked to find scope for solar energy utilization in the Indian textile industry. Abdel-Dayem et al. also found the potential of solar energy utilization in the textile industry [3]. These studies conclude that solar energy can herald enormous economic benefits for textile industry. There is need for research in this area to mould the available technology for its greater exploitation. Not only in India but across the globe people are showing interest in use of solar energy in garment industry.

In this paper, an attempt has been made to carry-out the techno-economical analysis considering some environmental aspects and the feasibility study of on-site and off-site 2.5 MW parabolic trough collector solar power plants for garment zone of Sitapura industrial area, Jaipur. The onsite power plant has capacity to generate 8.47 GWh electricity in first year of operation at 38.58% capacity factor while offsite power plant can generate 8.87 GWh electricity at 40.38% capacity factor for meeting the energy demand of the sector.

2. Energy demand of garment zone

A questionnaire based survey was carried out in July to September, 2011 for energy demand estimation in garment zone of Sitapura, Jaipur. After the primary survey questionnaire was modified and used. Questionnaire comprised of demand of heat

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Table 1
Monthly average electricity requirement of the industries.

S no	Industry	Average on-season demand (kWh/month)	Average off-season demand (kWh/month)	Average annual demand (kWh/month)
1	A & A Exports	4317.85	3888.4	4138.91
2	Alacrity	18344.57	12717.4	16000
3	Aman Exports	26045.00	22039.6	24376.08
4	Aravali Exports	2487.42	1954.8	2265.5
5	Arayavat	16579.42	14600.4	15754.83
6	Cheer Sagar	20998.14	17781.4	19657.83
7	Cot Fab India	10291.28	9246	9855.75
8	Garmef	11465.42	7948.2	10000
9	Goyal Arts	8599.14	5961.4	7500
10	Gupta Feb tech pvt. Ltd.	33930.57	17989.2	27288.33
11	Hariram Exports	11909.42	8221	10372.58
12	Harsha International	10526.57	9425.2	10067.67
13	High Choice	20671.57	16988.8	19137.08
14	Innovation	20637.85	14307.2	18000
15	Jalaj Exports	2866.28	1987	2500
16	Jimmy Mode International	12790.42	4394.6	9292.167
17	Kagzi Exports	24571.57	18297.6	21957.42
18	Kailino Arts	11465.42	7948.2	10000
19	Khatri Exports	2119.42	1662.6	1929.083
20	Leela Niryat	11578.00	9598.6	10753.25
21	Lodha Impex-1	22180.8	13841.6	18706.17
22	Lodha Impex-2	37835.71	26229.8	33000
23	M. K. Exim	9745.71	6756.4	8500
24	MA'AM Arts	20202.85	15850.2	18389.25
25	Miya bazaz	8248.43	6393.8	7475.66
26	Nash Fashion	22930.71	15897	20000
27	NSPL IMPEX	1607.14	1219.6	1445.66
28	Ocean Exim India	10260.14	7529.8	9122.5
29	Paisley Industries	5077.57	3800.4	4545.41
30	Pawan Febtech	26594	11616.2	20353.25
31	Priya International	1719.71	1192.2	1500
32	Ratan Textile	18724.14	15281.2	17289.58
33	Registan Exports	17198.14	11922.6	15000
34	Rupayan-1	18520.14	13226.6	16314.5
35	Rupayan-2	5732.71	3974.4	5000
36	S. K. India International	6317.57	4796.2	5683.67
37	Sabby Exports	7593.71	6418	7103.83
38	Savi Exports	23433.42	10618.2	18093.75
39	Shekhawati Impex	1719.71	1192.2	1500
40	Shivangi Inc. Exports	10761.28	5374.8	8516.91
41	Shri Ram Omex	21578.57	15404.4	19006
42	Somani Fabric	17167.85	13957.6	15830.25
43	Suprint Textile	8584	7294.2	8046.58
44	The Choice fashion	28245.28	12898.4	21850.75
	Total energy demand	**634175.07**	**439643.5**	**553120.3**

and power for individual industry, number of different type of machines, their energy consumption and duration of operation etc. Estimated average energy requirement for 44 industries of garment zone is summarized for the five months of off-season from May to September and for seven months of on-season from January to April and October to December and shown in Table 1. The monthly average energy demand of the year is 553,120.3 kWh.

3. Proposed solar thermal system

The estimated peak power requirement of the zone was 2.22 MW in the month of February 2011 and considering the expected increase in the future a 2.5 MW parabolic trough collector solar power system is considered for garments zone. In Parabolic trough systems the heat transfer fluid (HTF) is heated up to almost 400 °C and pumped to the steam generator, which in turn, is connected to a steam turbine. The solar power plant is composed of three system viz. solar field, power block and piping system. Technical specifications of the power plant are discussed in this section.

3.1. Design of solar field

A parabolic trough power plant's solar field consists of a large, modular array of single-axis-tracking parabolic trough solar collectors. Many parallel rows of these solar collectors span across the solar field, aligned on a north–south horizontal axis. The basic component of a parabolic trough solar field is the solar collector assembly (SCA). Size/number of each component are shown in Table 2.

3.2. Power block

Power block of the solar power plant composed of a turbine, steam generator and preheater, reheater, air cooled steam condenser and pumping system.

3.2.1. Turbine

Siemens "SST-120" turbine is selected for the solar power plant. It is a condensing type steam turbine. Technical specifications of the turbine are given in Table 3.

Table 2
Design of solar field.

S. no	Items	Size/number
1	Aperture area required for solar field collectors	18800 m^2
2	Number of solar collector assembly loops	8
3	Number of solar collector assembly	32
4	Number of solar collector elements	256
5	Number of receiver tubes	768
6	Distance between two SCA rows	12 m
7	Land required for solar field	15.6 Acres
8	Area required for power block	300 m^2
9	Land required for solar power plant	15.76 Acres
10	Heat transfer fluid used	Therminol VP-1
11	Mass flow rate of heat transfer fluid	40 kg/s
12	Quantity of heat transfer fluid required	18.75 T
13	Tracking system	
	Tracking	East west single axis tracking
	Actuator	SkyTrakker^{TM}
	Number of actuators required	32

Table 3
Technical specifications of the turbine.

S. no.	Parameters	Values
1	Condition of input steam at stop valve	
	Nominal pressure, bar (abs)	100
	Nominal temperature, °C	350
	Nominal steam consumption, tons/hour	36
2	Output steam nominal pressure, bar (abs)	1.2
3	Turbine rotor, rpm	7500
	Output reducer rotor, rpm	3000
4	Turbine setting efficiency, %	39.3
5	Generator efficiency, %	96
6	Turbine overall efficiency, %	37.7
7	Electrical power at generator terminal, kW	2500

3.2.2. Steam generator and preheater

The steam generator selected for the solar power plant is a tube in shell type heat exchanger for combined water preheating and steam generation. Specifications of the steam generator and preheater are given in Table 4.

3.2.3. Reheater

A shall in tube type reheater is selected to reheat the steam between low pressure and high pressure turbine. Technical specifications of the reheater for reheating of steam between low pressure and high pressure are given in Table 5.

Table 4
Technical specifications of the steam generator and preheater.

S no	Parameters	Values
1	Temperature of the HTF at inlet of steam generator, °C	390
2	Temperature of the HTF at outlet of steam preheater, °C	281
3	Steam pressure at desired output, bar (abs)	103
4	Steam temperature at steam generator outlet, °C	375
5	Water temperature at preheater inlet, °C	105
6	Flow of steam at desired output, kg/s	10

Table 5
Technical specifications of reheater.

S. no	Parameters	Value
1	Temperature of the HTF at inlet of reheater, °C	390
2	Temperature of the HTF at outlet of reheater, °C	240
3	Steam pressure at desired output, bar (abs)	18.5
4	Steam temperature at reheater outlet, °C	371
5	Steam temperature at reheater inlet, °C	220
6	Flow of steam at desired output, kg/s	10

Table 6
Pumps required in the solar power plant.

S. No.	Pump	Pump power (kW)
1	Heat transfer fluid pump	111.73
2	Pump for working fluid pumping	140.04
3	Feeding water to the demineralization plant	18.25
4	Feeding water to the overhead tank from the underground condensate water tank	18.25

Table 7
Pipe sizing.

S. no.	Pipe	Pipe Size (mm)		
		Inner diameter	Outer diameter	Pipe thickness
1	Between preheater and steam generator	32.6	42.2	4.8
2	Between steam generator & super heater	84.8	101.6	8
3	After super heater	73.7	88.9	7.6
4	Before reheater	154.1	168.3	7.1
5	After reheater	178.4	193.7	7.64
6	Before condenser	391.6	400	4.2
7	Between condenser and preheater	24.3	33.4	4.55
8	Heat transfer fluid pipe	54.7	60.3	2.8

3.2.4. Pumps and pumping system

There are four pumps used in the solar power plant. Details of the pumps are given in Table 6.

3.3. Pipes and piping system

In this solar power plant there are two piping systems are used, one for heat transfer fluid and other for working fluid. The sizes of the pipes are given in Table 7.

4. Economic assessment

4.1. Project cost

Project cost is decided by taking quotations from different suppliers and from various case studies of solar power plants all over the world. These costs are compared with the capital cost norms recommended by the Indian Central Electricity Regulatory Commission [4] as shown in Table 8.

Project cost quoted by ACME [7] is used for financial analysis. In Table 9 gives the detail project cost for 2.5 MW parabolic trough collector power plant.

4.2. Operation and maintenance cost

Operation and maintenance costs include all type of operation & maintenance related cost along with costs for fuels. Solar energy plants tend to be very low on operating costs in comparison with fossil fuel generators. This cost has been estimated for the PTC power plant and break up of this is presented in Table 10. The World Bank has recommended certain regulatory and financial

Table 8
Capital cost norms of the Indian Central Electricity Regulatory Commission.

Item description	Capital cost norm for solar thermal power plant (Million INR /MW)
Direct cost	**134.8**
Solar block and power block	129.0
Land	1.8
General civil and structural works	4.0
Indirect cost	**18.2**
Preliminary and pre-operative expenses, contingency and interest during construction	
Total capital cost	**153.0**

Table 9
Project cost for PTC power plant.

S. no.	Particular	Cost Million INR
1	Mirrors/frames/HTF/receivers/balance of system of solar field	199.5
	Solar field construction/Engineering procurement & construction	10
	Total solar field cost	**209.5**
2	Steam turbine generator/mechanical & electrical equipment	87.5
	Construction for power block	53
	Power block total cost	**140.5**
3	Preliminary/pre-operation expanse	24
4	Contingency	7
5	Interest during construction	17.75
	Total project cost	**399**

assumptions [5] for assessment of concentrated solar power economics for India as shown in Table 11.

4.3. Capacity factor

Capacity factor measures the annual efficiency of power generation facilities, specifically the actual percentage of power that a facility produces at its maximum rated power capacity as measured over 365 days/year for 24 h. For solar plants, it is below 50% because after all, the solar radiations are available only for half of the time. The equation for estimating capacity factor of solar power plant is [6]

$$CF = \frac{\lambda}{\tau}\frac{SE}{P_{rated}}$$

where SE=Electricity generated in a whole year; (kWh); λ=Conversion factor from kWh to J; τ=Time (seconds) in one year; P_{rated}=Nominal electrical power of the turbine (W).

Estimated yearly average value of capacity factor is 38.58% for the onsite solar power plant.

Similarly, monthly capacity factor and monthly energy yield has been estimated for onsite power plant as shown in Table 12.

4.4. Capital recovery factor

A capital recovery factor (CRF) converts a present value into a stream of equal annual payments over a specified time, at a specified discount rate.

$$F_R = \left(\frac{I_r(1+I_r\Delta t)^n}{(1+I_r\Delta t)^n - 1}\right)$$

where I_r=Discount rate; Δt=Interest cycle; n=System life time.

For system lifetime of 25 years and calculating interest on a yearly basis, capital recovery factor for 10% discount rate is 11.02%. Capital recovery factor depends upon the discount rate. The representative values of capital recovery factor for different discount rates are calculated and shown in Table 13.

4.5. Levelised cost of energy (LCOE)

Levelised cost of energy is equivalent to the average price consumers would have to pay to exactly repay the investor for capital, O&M and fuel costs with a rate of return equal to the discount rate. Thus LCOE is minimum price at which energy must be sold for an energy project to get break even in the estimated life time. LCOE approach often used to help assess economic profitability of a planned electricity generation plant or to compare two

Table 10
Operation and maintenance cost.

Particular	Cost (million INR)
Onsite staff	1.80
Maintenance and repair	
Solar field	0.75
HTF system	0.76
TES system	0.80
Power block	1.10
Office and Administration	0.15
Contract service	0.40
Miscellaneous cost	0.50
Total annual O&M cost	6.26

Table 12
Monthly capacity factor, energy yield and sunshine hours.

Month	Monthly sum of DNI (kWh/m^2)	Energy yield (kWh)	Sunshine (h)	Capacity factor (%)
Jan	189	793,074	744	42.64
Feb	175	734,328	696	42.20
Mar	190	797,270	744	42.86
Apr	185	776,290	720	43.13
May	187	784,682	744	42.19
Jun	168	704,955	720	39.16
Jul	119	499,343	744	26.85
Aug	110	461,578	744	24.82
Sep	150	629,424	720	34.97
Oct	180	755,309	744	40.61
Nov	182	763,701	720	42.43
Dec	184	772,093	744	41.51
Annual average	168.25	706,004	732	38.58
Annual sum	2019	8472,047	8760	38.58

Table 13
Capital recovery factor for different discount rates.

S. no.	**Discount rate (I_r) (%/year)**	**Capital recovery factor (F_R) (%/year)**
1	4	6.40
2	5	7.09
3	7	8.58
4	10	11.02

Table 11
Regulatory and financial assumptions for assessment of CSP economics in India used by World Bank.

S. no.	**Assumptions used by World Bank**	
1	Analysis period	25 years
2	Inflation rate (%)	5.5
3	Real discount rate	15%
4	Minimum alternative tax	18.5%
5	Property tax	0%
6	VAT+excise duties	5% on 100% of Direct Costs
7	Depreciation schedule	7% first 10 years |1.33% afterwards
8	Loan term	12 years
9	Loan rate	11.75%
10	Debt fraction	70%
11	Return on equity	19%
12	Min required IRR	15%
13	Min required debt-service coverage ratio	1.5
14	Exchange @ Rs/US$	45.0 Rs/$

or more alternative plant investments. Typically LCOE is calculated over the lifetime of project and given in the units of currency per kilowatt-hour (e.g., €/kWh).

$$\mathrm{LCOE}=\frac{(F_R+O_f)}{F_C}\frac{C_o}{P}+C_{o\&m}+\sum\frac{C_i}{\eta}$$

where F_R=Capital recovery factor (% per annum); O_f=Fixed O&M cost (% per annum); F_c=Capacity factor; C_o=Capital cost (INR); P=Installed capacity (kW); $C_{O\&M}$=Variable O&M cost (INR); C_i/η=Cost of inputs/$\eta_{conversion}$ (INR/kWh).

$\mathrm{LCOE}=INR\ 6.87/\mathrm{kWh}$

The estimated LCOE for 25 years of plant operation at 10% discount rate is Rs. 6.87/kWh for installed cost of Rs.159,600/kW.

Change in LCOE with discount rates for different life times is shown in Fig. 1.

4.6. Net present value

The difference between the present value of the benefits and the costs resulting from an investment is the Net Present Value (NPV) of the investment. A positive NPV means a positive surplus indicating that the financial position of the investor will be

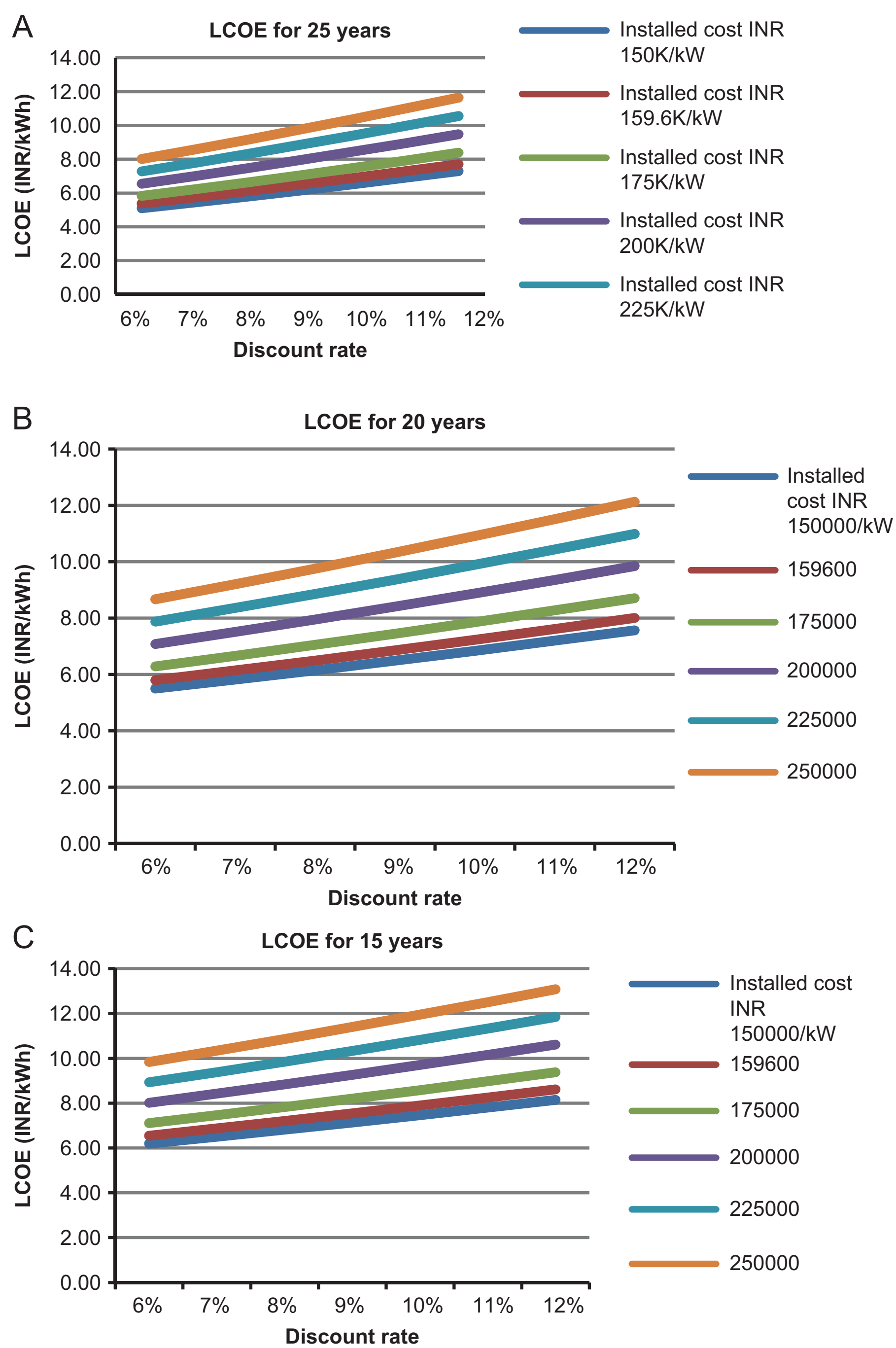

Fig. 1. (A) Variation of LCOE for 25 years life time. (B) Variation of LCOE for 20 years life time. (C) Variation of LCOE for 15 years life time.

Table 14
Financial performance indicators (All price in million INR).

	Power plant	
	On-site	Off-site
Pre tax analysis		
NPV @ 10 % discount rate (Million INR)	407.9	497.53
NPV @ 15 % discount rate (Million INR)	149.61	245.50
IRR (%)	20	27
Simple payback period (years)	4.77	3.67
Discounted payback period (years) @ 10% discount rate	6.85	4.82
Discounted payback period (years) @ 15% discount rate	9.15	5.78
Post tax analysis		
NPV @ 10% discount rate (Million INR)	372.77	468.12
NPV @ 15% discount rate (Million INR)	121.13	222.81
IRR (%)	19.21	25.31
Simple payback period (years)	5.01	3.86
Discounted payback period @10% (years)	7.36	5.14
Discounted payback period @15% (years)	10.20	6.24
Equity analysis pre-tax		
Debt fraction	70%	
Interest rate	11.75%	
NPV @ 10% (Million INR)	377.97	475.37
NPV @ 15% (Million INR)	193.91	278.29
IRR (%)	33.27%	53.46%
Simple payback period (years)	3.03	1.85
Discounted payback period @10% (years)	3.81	2.15
Discounted payback period @15% (years)	4.39	2.35
Debt Fraction=70%		
Interest rate=11.75%		
Equity analysis post-tax		
NPV @ 10% (Million INR)	342.88	446.00
NPV @ 15% (Million INR)	168.53	257.89
IRR (%)	30.07	49.10
Simple payback period (years)	3.38	2.01
Discounted payback period @10% (years)	4.36	2.37
Discounted payback period @15% (years)	5.12	2.60

improved by undertaking the project. Obviously, a negative NPV would indicate financial loss. An NPV of zero would mean that the present value of all benefits over the useful lifetime is equal to the present value of the costs. In mathematical terms,

$$\mathrm{NPV} = \sum_{j=0}^{n} \frac{B_j - C_j}{(1+i)^j}$$

where B_j=benefits at the end of period j; C_j=costs at the end of period j; n=useful life of the project; i=interest rate.

The equation of NPV involves subtracting of the costs from the benefits at any period and then multiplying the result by the single payment present worth factor for that period. Finally the NPV is determined by algebraically adding the result for all the periods under consideration (Table 14).

4.7. Internal rate of return

Internal Rate of return (IRR) is a widely-accepted discounted measure of investment worth and is used as an index of profitability for the appraisal of project. The IRR is defined as the rate of interest that equates the present value of a series of cash flows to zero. In other words, it is the interest rate at which the NPV of an investment is zero. Mathematically, the internal rate of return is the interest rate i^* that satisfies the equation

$$\mathrm{NPV}(i^*) = \sum_{j=0}^{n} \frac{B_n - C_n}{(1+i^*)^j} = 0$$

where B_n=Benefits associated with nth year; C_n=Cost associated with nth year.

5. Conclusion

In the present study, techno-economic evaluation of a 2.5 MW parabolic trough collector solar power plant for garment zone of Sitapura industrial area is performed. 15.6 acres solar collector field is designed for the power plant. The solar field has eight solar collector assembly Loops. Each loop has four solar collector assemblies. The solar field collects 9.2 MW heat. This heat is transferred to power block by heat transfer fluid. Therminol VP-1 is used as heat transfer fluid. 18.75 t of heat transfer fluid circulates in the solar field at the flow rate of 40 kg/s. This heat is taken by steam generator which is a tube-in-shall type heat exchanger. Steam generator supplies steam at 375 °C temperature and 103 bar pressure at the rate of 10 kg/s. The steam from steam generator is supplied to a 2.5 MW capacity turbine. The turbine selected is a condensing type steam turbine.

The power plant can generate 8.47 GWh/year in first year of operation at 38.58% capacity factor. 0.5% annual degradation is considered. Cumulative degradation after 25 years will be 11.01%. Due to degradation output of the power plant slightly goes down, after 25 years the estimate output will be 7.57 GWh/year. For 25 years operational life of plant, Levelised cost of energy (LCOE) is determined. The LCOE depends upon discount rate and operational life of the plant. For 25 years of plant life and 10% discount rate LCOE of the solar power plant is Rs 6.89/kWh. Sensitivity analysis of LCOE is performed with plant operational life, discount rate and per kW power plant cost. The results of sensitivity analysis are shown in Fig. 1(A–C).

For financial analysis of the solar power plant internal rate of return (IRR), net present value (NPV) and payback periods are taken as indicators of financial performance. Financial performance indicators are analyzed for four financial cases i.e., Pre-tax analysis, Post-tax analysis, Equity analysis pre-tax and equity analysis post-tax. From the financial analysis the project seems very attractive with 26.48% Post-tax IRR and NPV of 50.6 Cr INR.

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Mevin Chandel, G.D. Agrawal, Anuj Mathur*
Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur -302017, India
E-mail address: anujmathur89@yahoo.com (A. Mathur).

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